
VLBNO Beam Design/Simulations and Event Rates

*FNAL-BNL joint study on Long Baseline
Neutrinos 09/16/2006*

Mary Bishai (BNL)

mbishai@bnl.gov



FNAL-BNL Joint Study

The Chairs: Sally Dawson (BNL) and Hugh Montgomery (FNAL).

Advisory Committee: Franco Cervelli (INFN) Milind Diwan (BNL); co-leader, Maury Goodman (ANL), Bonnie Fleming (Yale), Karsten Heeger (LBL), Takaaki Kajita (Tokyo), Josh Klein (Texas), Steve Parke (FNAL), Gina Rameika (FNAL); co-leader

The Charge: Compare the neutrino oscillation physics potential of (report to NuSAG by Oct. 2006):

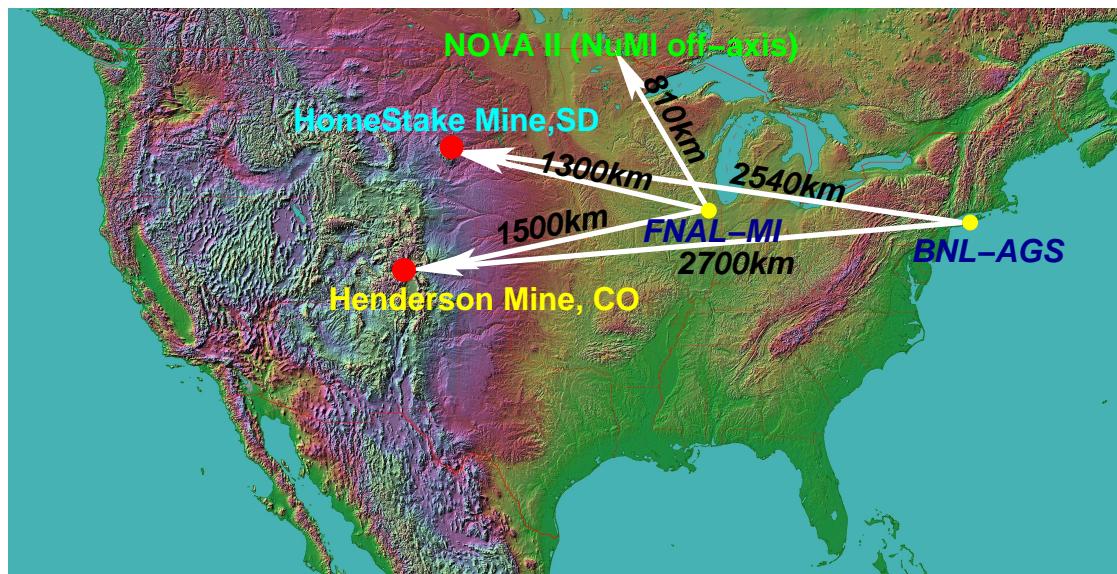
- 1) A broad-band proposal using either an upgraded beam of around 1 MW from the current Fermilab accelerator complex or a future Fermilab Proton Driver (PD) neutrino beam aimed at a DUSEL-based detector. Compare these results with those previously obtained for the BNL VLBNO program.**
- 2) Off-Axis next generation options using a 1-2 MW neutrino beam from Fermilab and a liquid argon detector at either DUSEL or as a second detector for the NOVA experiment.**

Status: Documents at <http://nwg.phy.bnl.gov/~diwan/nwg/fnal-bnl/>

BEAM SPECIFICATIONS

"Fermilab Proton Projections for Long-Baseline Neutrino Beams," Robert Zwaska for the SNuMI planning group, July 17, 2006. FNAL-Beams-DOC-2393

Beam Options/Baselines



The following beam options and baselines are considered:

Off axis beams using the 120 GeV NuMI beamline at FNAL to sites at 810km.

A 28 GeV on-axis Wide-Band Beam (WBB) beam from the BNL AGS to DUSEL sites at 2540 and 2700 km.

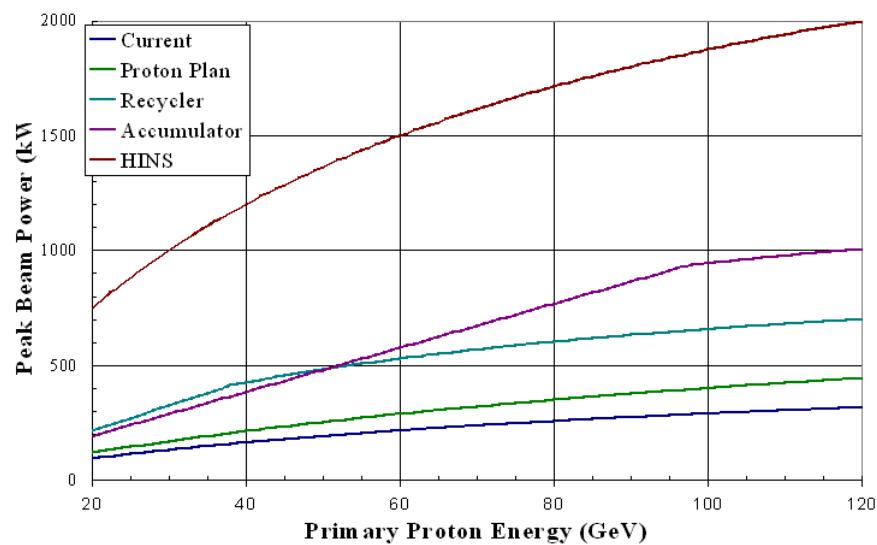
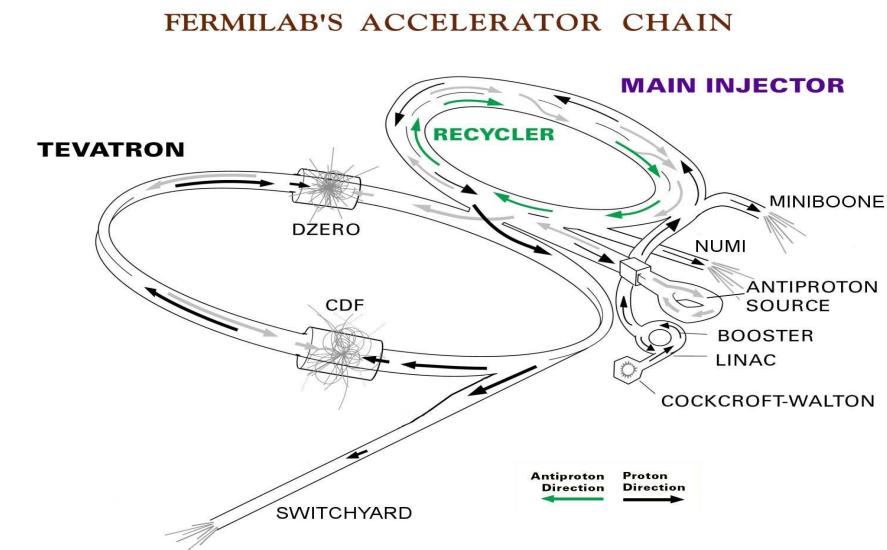
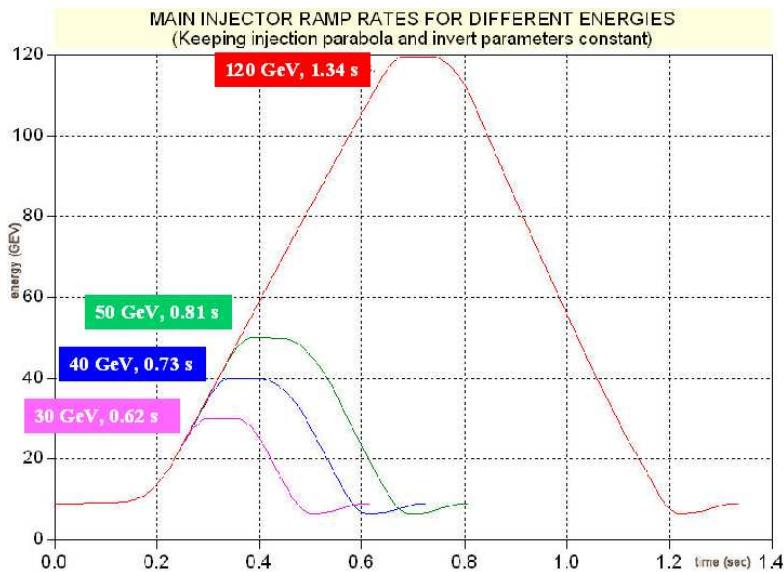
A newly designed on-axis \leq 120 GeV Wide Band Low Energy (WBLE) beam and beamline from the FNAL MI to DUSEL sites at 1300km and 1500km.

For the current study we will concentrate on beam options from FNAL

FNAL Beam Specs: E & Power

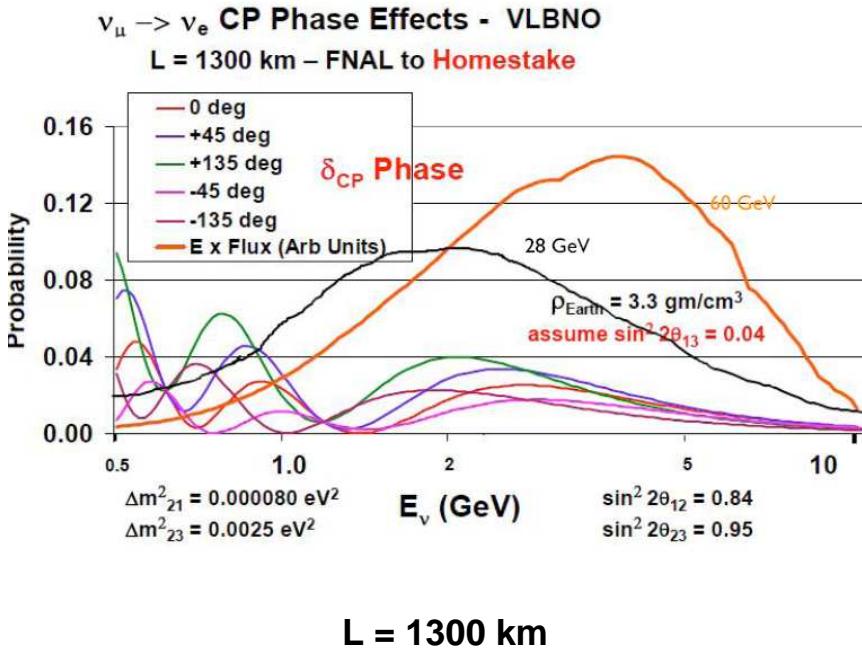
Incremental upgrades possible
(no proton driver):

Use the existing recycler and anti-proton accumulator to store protons from the 8 GeV 15 Hz Booster during the MI cycle then inject to MI bringing intensity up to $6 \times 10^{13} p/\text{spill}$.



WBLE Beam Design Requirements

The design specifications of a new WBLE beam based at the Fermilab MI are driven by the physics of $\nu_\mu \rightarrow \nu_e$ oscillations:

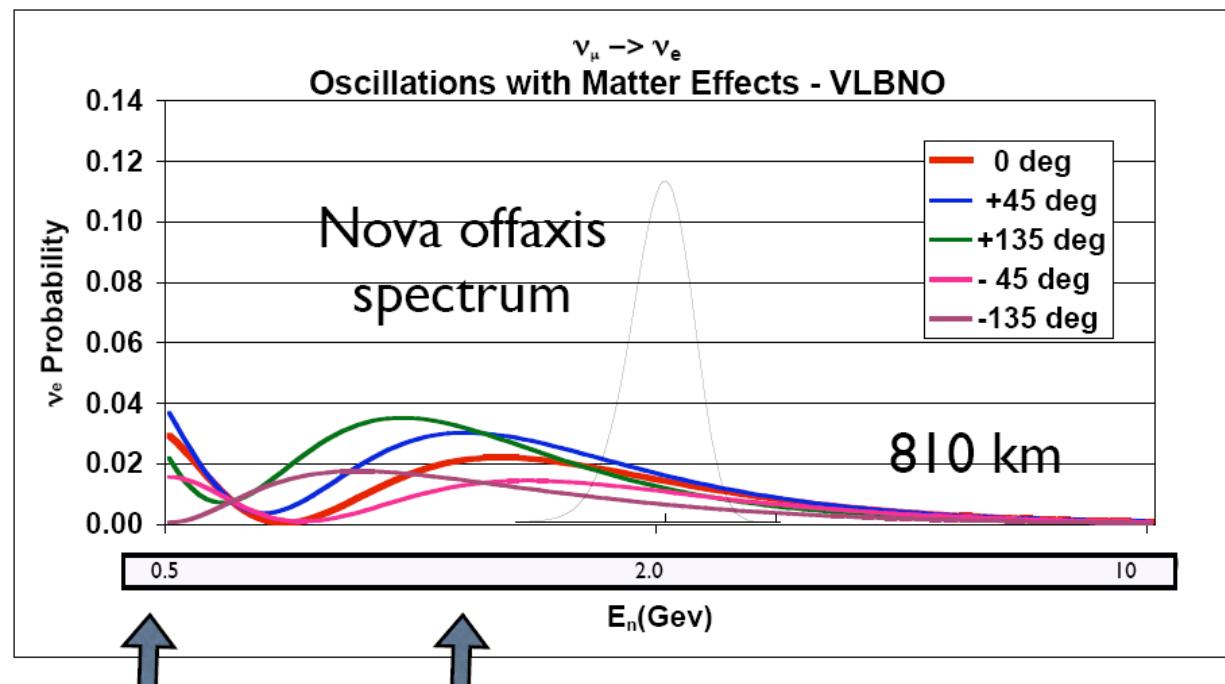


Requirements:

- Maximal possible neutrino fluxes to encompass the 1st and 2nd oscillation nodes, with maxima at 2.4 and 0.8 GeV.
- High purity ν_μ beam with negligible ν_e

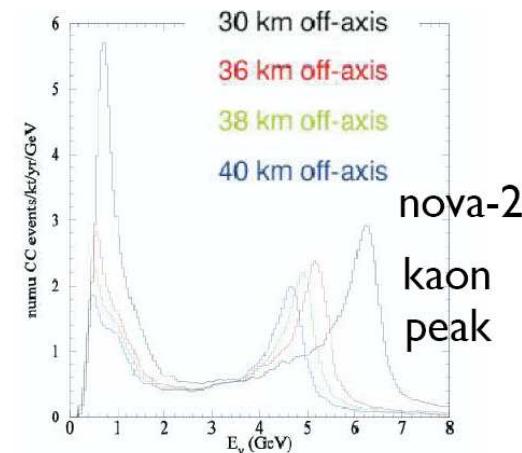
-Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV where there is no sensitivity to the oscillation parameters is highly desirable.

Off-axis Beam Specs at $L = 810$ km



Second NOVA detector positioned at a larger off-axis angle to access 2nd oscillation maximum at ~ 0.5 GeV.

Need excellent NC background rejection for backgrounds from higher energy kaon peak.



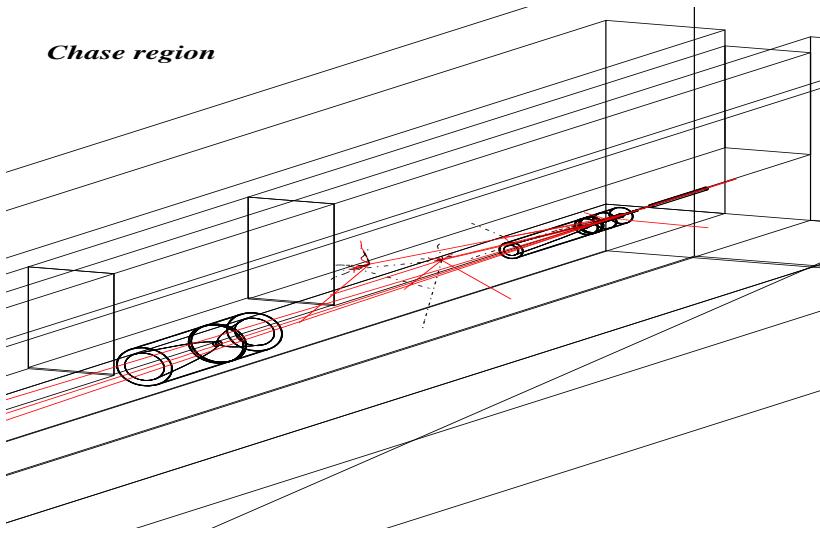
BEAMLINE DESIGN/SIMULATIONS

"Target System for a Long Baseline Neutrino Beam," N. Simos, H. Kirk, J. Gallardo, S. Kahn, N. Mokhov.
June 26, 2006.

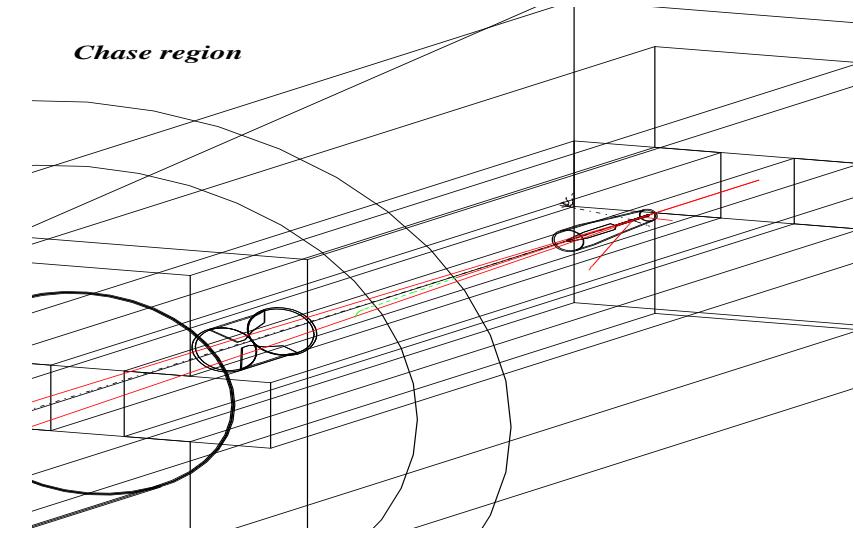
"Simulation of a Wide-band Low-Energy Neutrino Beam for Very Long Baseline Neutrino Oscillation
Experiments," M. Bishai, J. Heim, C. Lewis, A. D. Marino, B. Viren, F. Yumiceva, July 20, 2006

NuMI/WBLE simulation

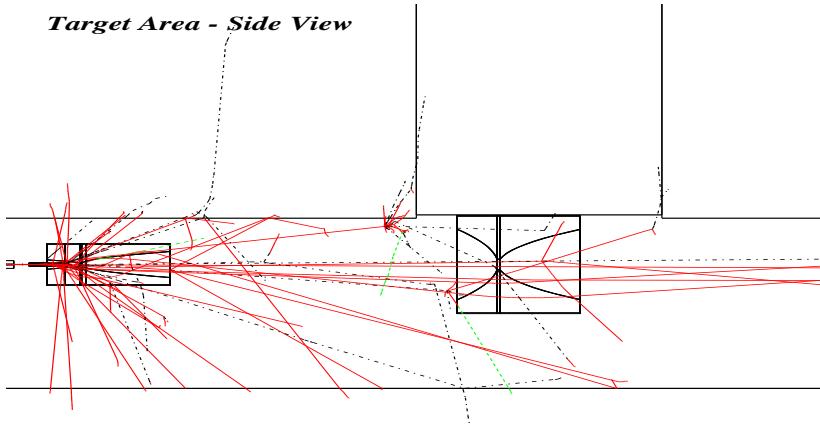
NuMI horns/target with 120 GeV p+



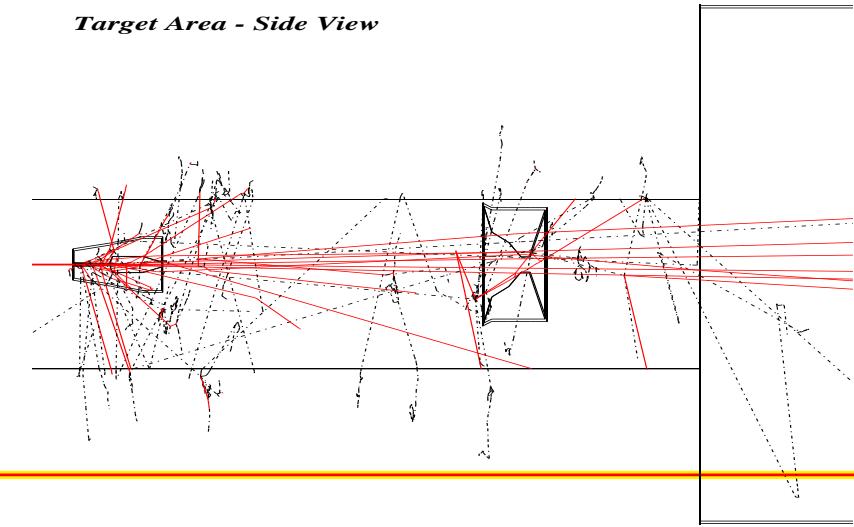
WBLE horns/target with 120 GeV p+



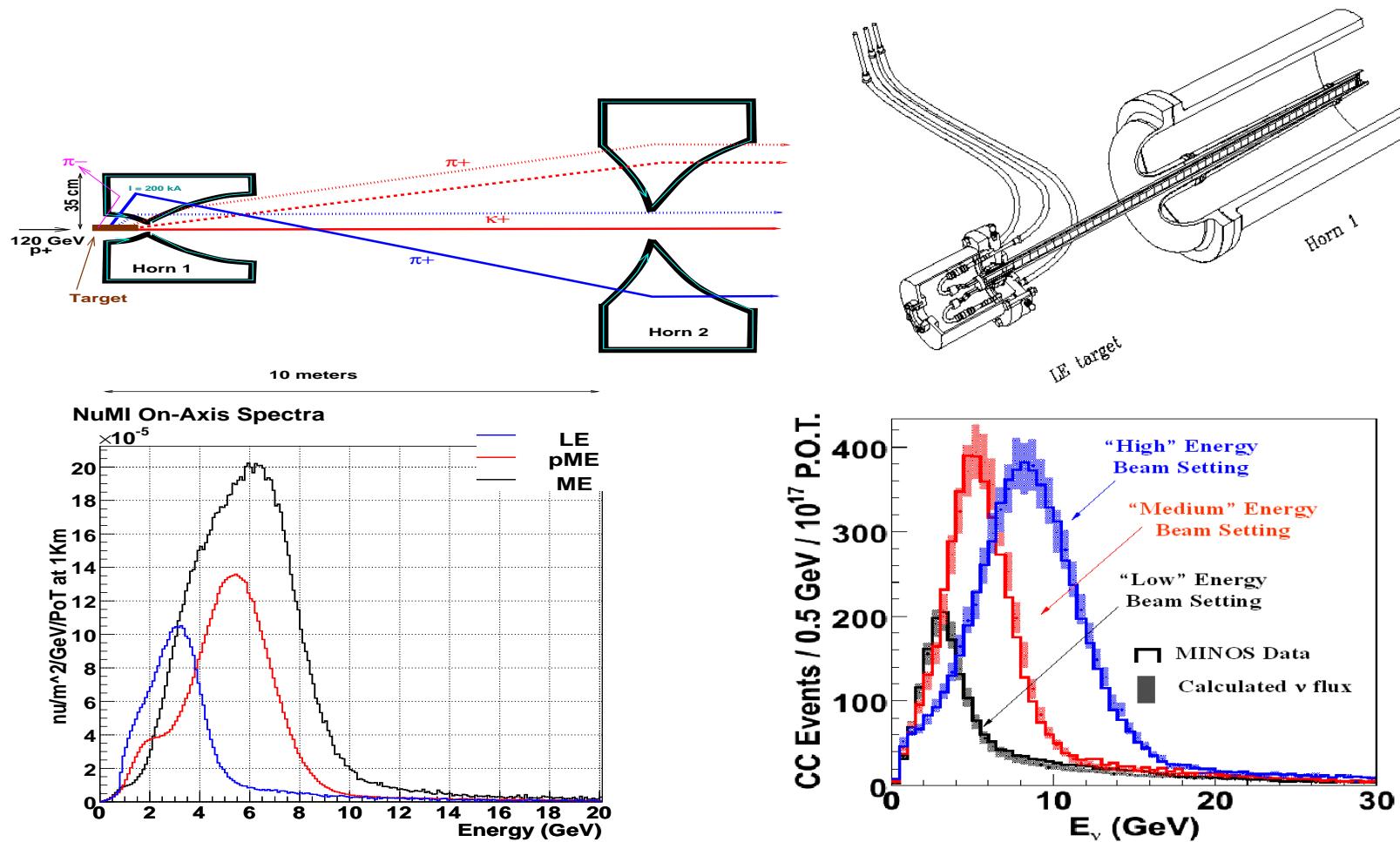
Target Area - Side View



Target Area - Side View



NuMI Beam Spectra



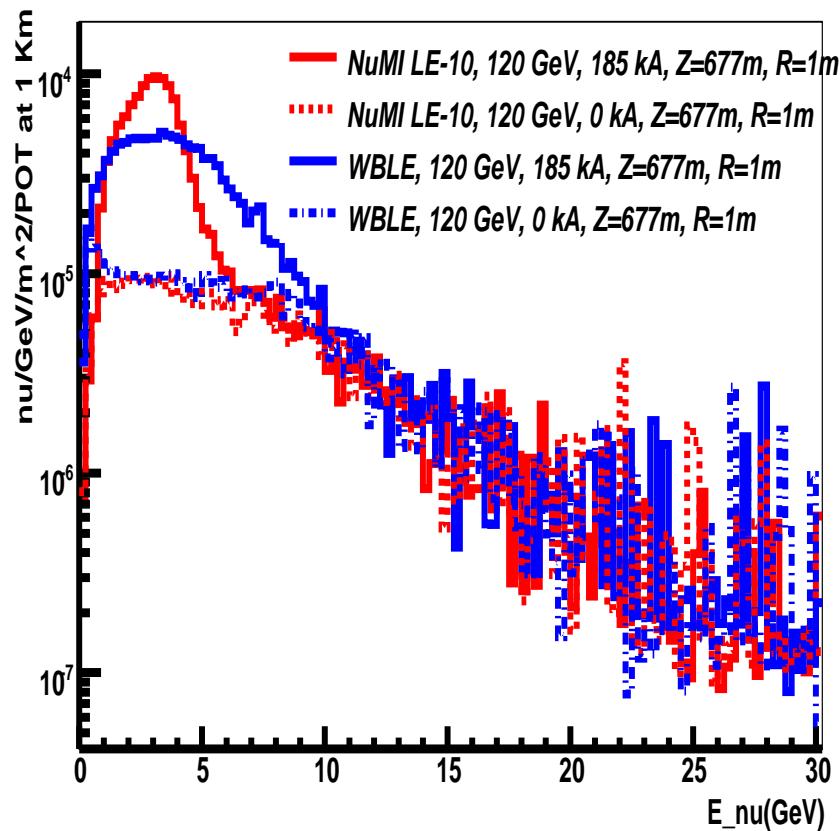
Target 45cm into Horn 1 (LE), -100cm from LE (pME), -250cm from LE (pHE)

-100 cm from LE and Horn 2 moved 3m further down (ME)

NuMI LE vs WBLE

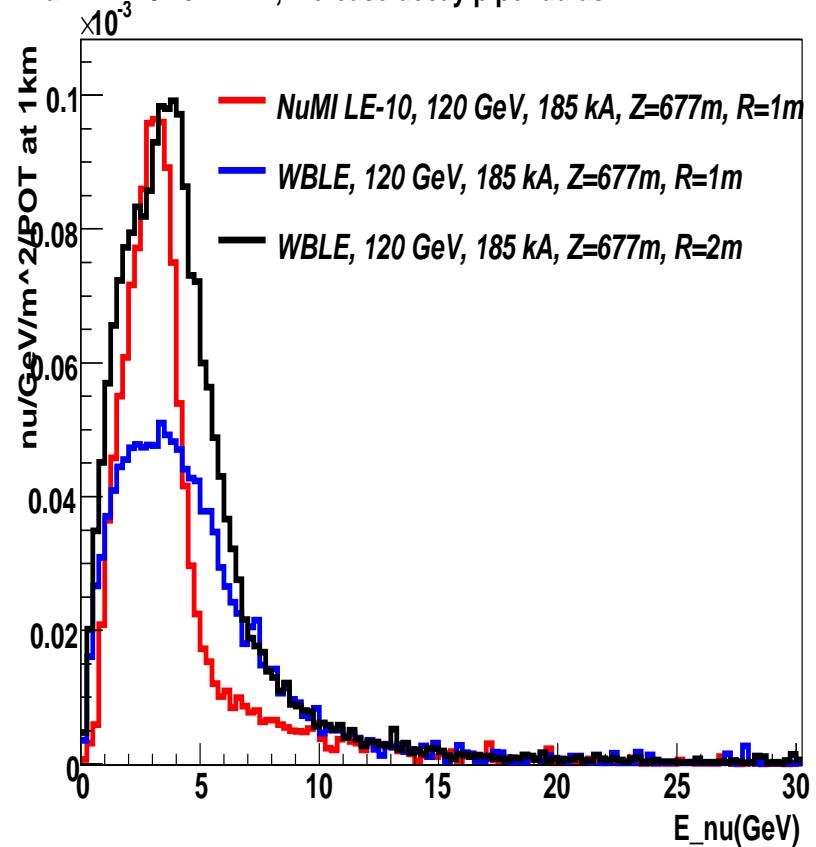
R and *Z* refer to the geometry of the decay volume which is cylindrical.

NuMI LE-10 vs WBLE spectra



1m radius decay pipe

NuMI LE-10 vs WBLE, increase decay pipe radius



increase to 2m radius

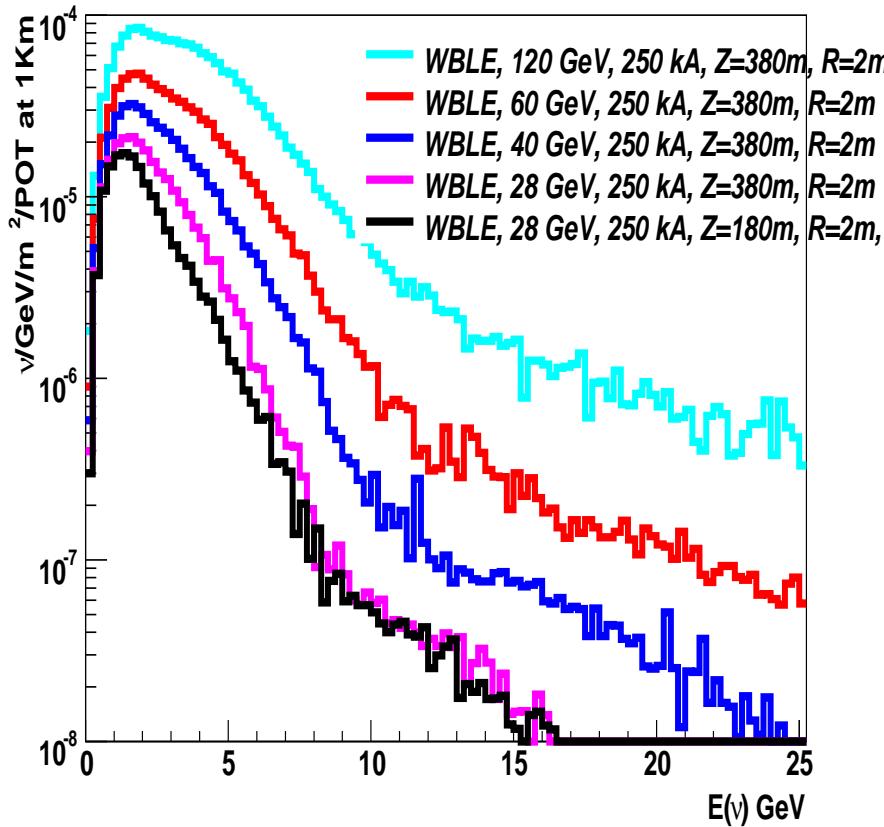
Larger diameter decay pipe = more flux at low E.

WBLE Beam Spectra for VLBNO

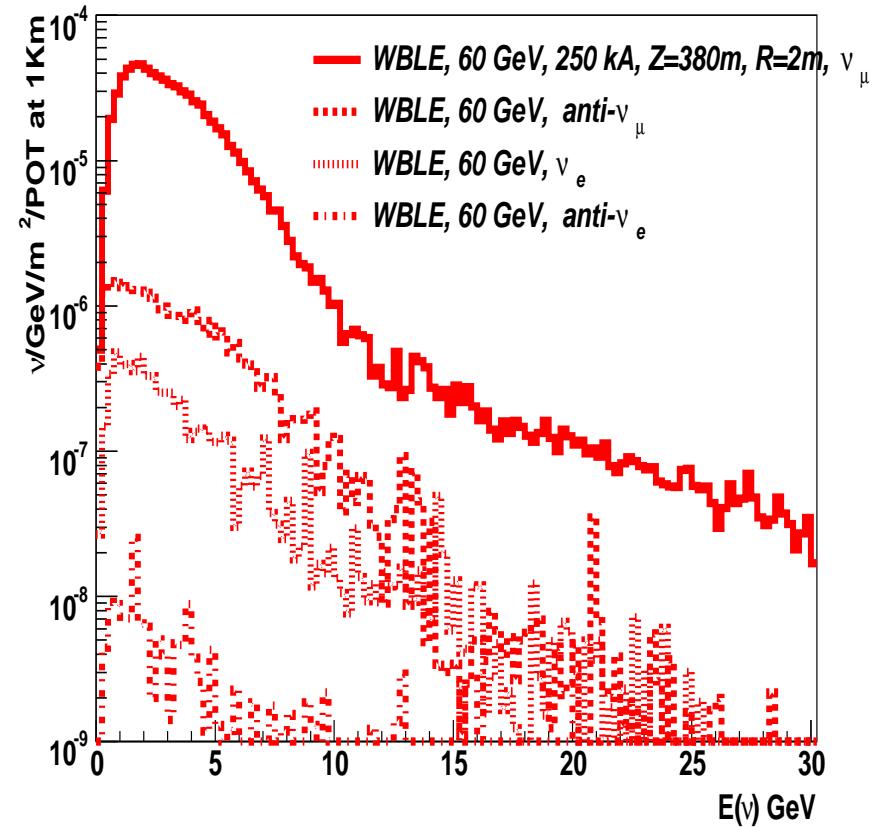
Decay pipe radius chosen to be 2m.

Siting restrictions \Rightarrow decay pipe is ≤ 400 m in length

WBLE beam, different energies, decay tunnels



WBLE spectra at 60 GeV



INTERACTION RATES

"Event Rates for Off Axis NuMI Experiments," B. Viren, June 8, 2006. BNL-76869-2006-IR. hep-ex/0608059.

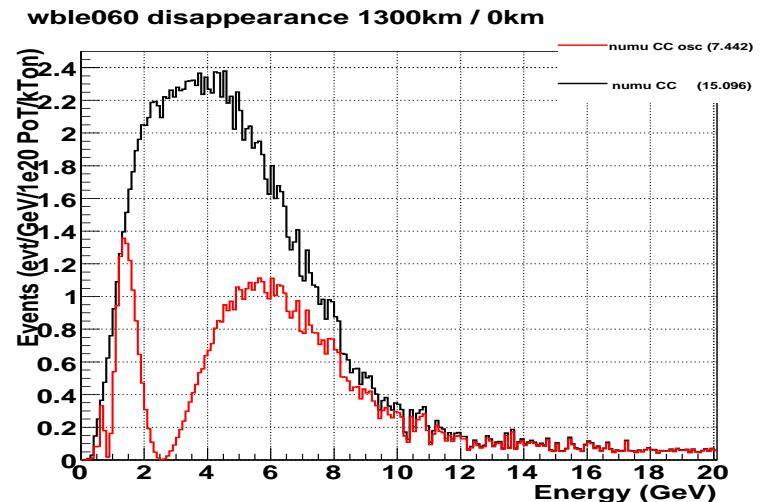
ν_μ Disappearance Rates

NO DETECTOR MODEL.

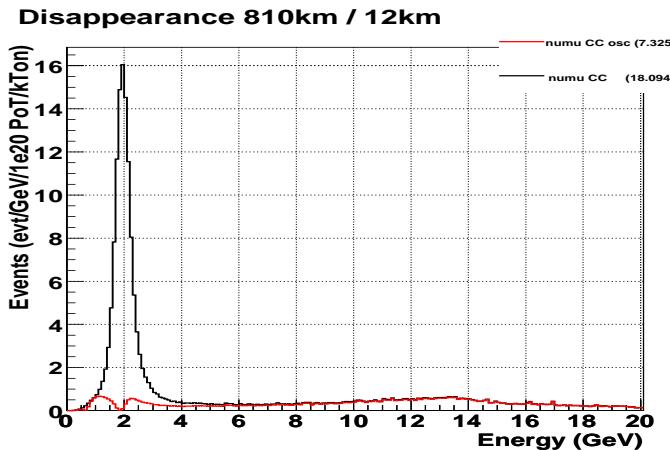
$-\nu_\mu$ CC no osc.

$-\nu_\mu$ CC with osc.

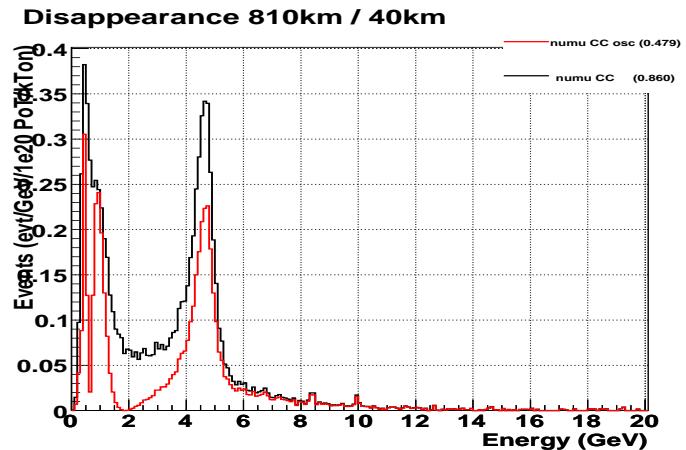
WBLE 60 GeV, 1300 km on-axis



NOVA Detector 1 810 km



NOVA Detector 2 810 km



Off-axis ν_e Appearance Rates

$$\sin^2 2\theta_{13} = 0.04$$

-NC π^0 from NUANCE

-CC $\nu_\mu \rightarrow \nu_e$

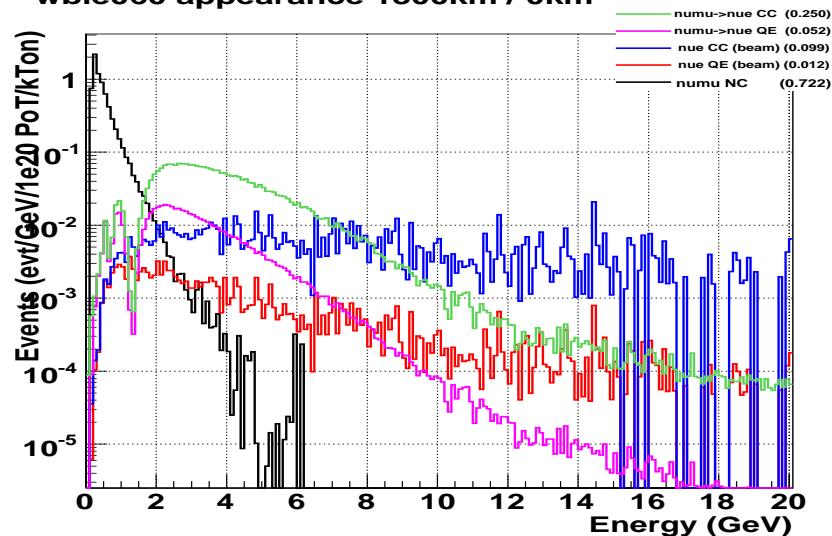
-QE $\nu_\mu \rightarrow \nu_e$

-CC beam ν_e

-QE beam ν_e

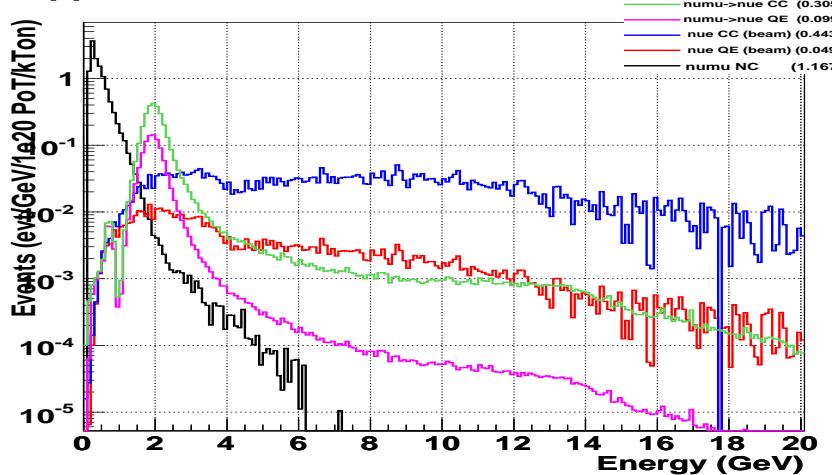
WBLE 60 GeV, 1300 km

wble060 appearance 1300km / 0km



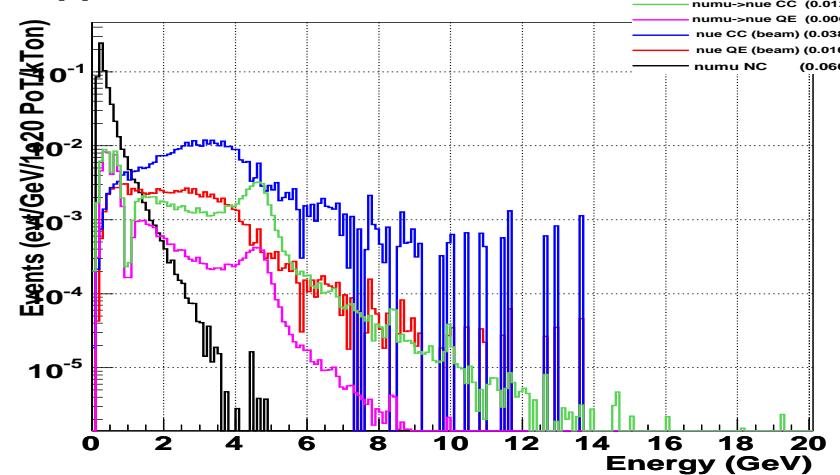
NOVA D1 810 km

Appearance 810km / 12km



NOVA D2 810 km

Appearance 810km / 40km



Rate Summary Tables

Rates are per 10^{20} POT. kT integrated from 0 - 20 GeV:

Beam	ν_μ CC	ν_μ CC osc	ν_e CC beam	ν_e QE beam	NC-1 π^0	$\nu_\mu \rightarrow \nu_e$ CC	$\nu_\mu \rightarrow \nu_e$ QE
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NuMI ME off axis at 810 km

0 km	248.0	225.0	1.80	0.0914	6.96	1.40	0.188
6 km	71.6	47.0	1.068	0.0770	3.194	0.879	0.171
12 km	18.1	7.33	0.443	0.0485	1.168	0.305	0.099
30 km	1.84	1.12	0.0730	0.0152	0.135	0.0216	0.0108
40 km	0.860	0.479	0.0378	0.0097	0.0605	0.0121	0.0057

WBLE on axis at 1300 km with decay pipe 2m radius 380 m length

120 GeV	39.0	26.0	0.427	0.030	1.624	0.566	0.105
60 GeV	15.1	7.4	0.099	0.012	0.722	0.250	0.052
40 GeV	7.28	3.02	0.042	0.007	0.403	0.134	0.031

$$\text{Number of protons}(10^{20}) = \frac{1000 \times \text{Beam Power (MW)} \cdot \text{time}(10^7 \text{s})}{1.602E_p \text{ (GeV)}}$$

Interaction Rates in MW.kT. 10^7 s

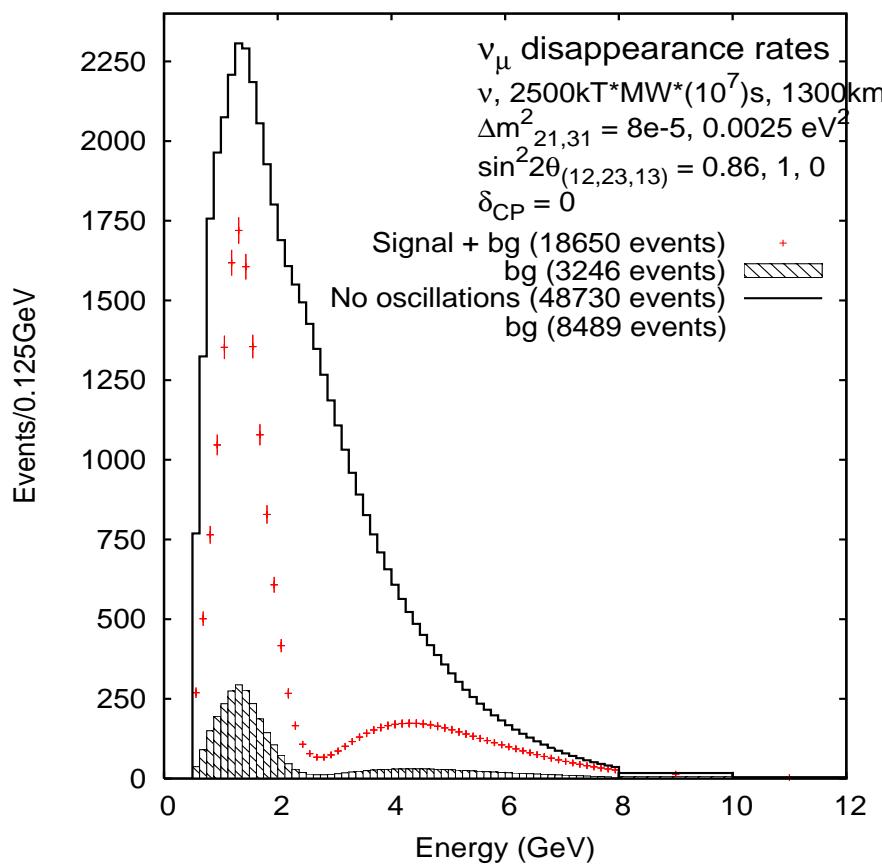
Beam Scenario	Decay Pipe (radius,length)	Total ν_μ CC rate /(10^{20} pot.kT)	Total ν_μ CC rate /(MW.kT. 10^7 s)	Total ν_μ QE rate /(MW.kT H_2O . 10^7 s)
NuMI LE at a distance of 735 km - on-axis				
LE-10 on-axis	(1m,677m)	82	427	56
NuMI ME at a distance of 810 km - off axis				
' 0km o.a.	(1m,677m)	248	1290	
6km o.a.	(1m,677m)	71.6	372	
12km o.a.	(1m,677m)	18.1	94	
30km o.a.	(1m,677m)	1.84	9.57	
40km o.a.	(1m,677m)	0.86	4.47	
WBLE at a distance of 1300 km - on-axis				
120 GeV	(2m,380m)	44	228	27.4
60 GeV	(2m,380m)	16	164	25.1
40 GeV	(2m,380m)	7.6	120	21.5
28 GeV	(2m,380m)	3.6	80	17.3
28 GeV (BNL study)	(2m,180m)	3.5	78	16.2

WBLE ν_μ Disappearance Spectra

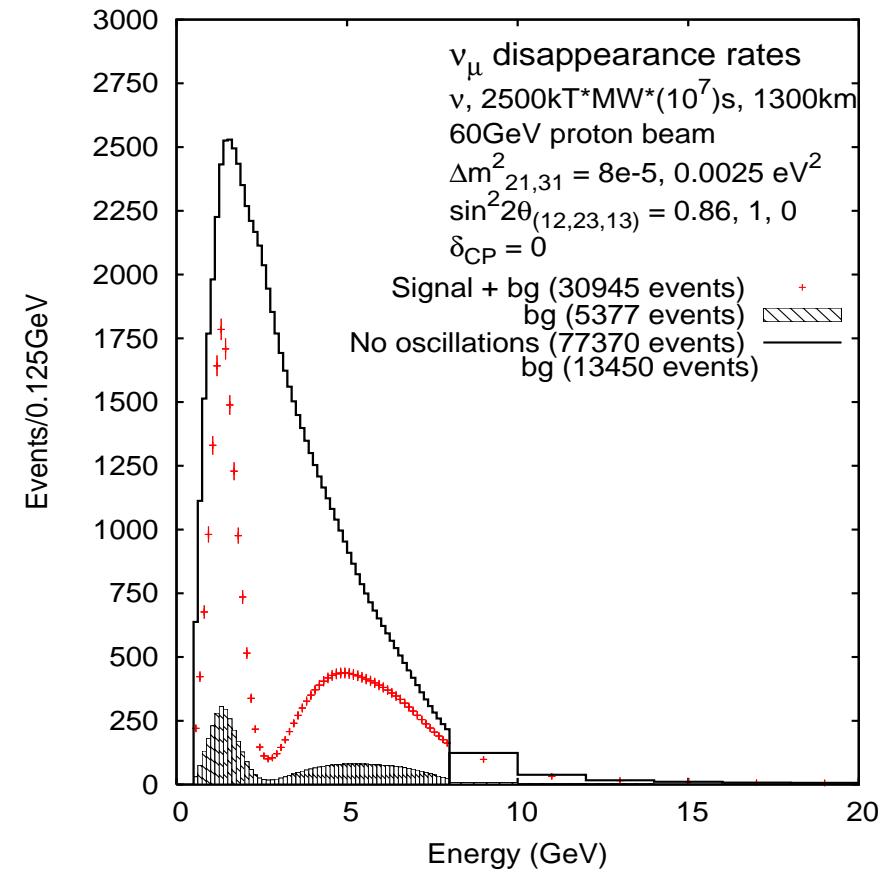
Parameterized Water Cerenkov Model in GLoBES.

1300km at 2500 MW.kT. 10^7 s.

WBB 28 GeV



WBLE 60 GeV

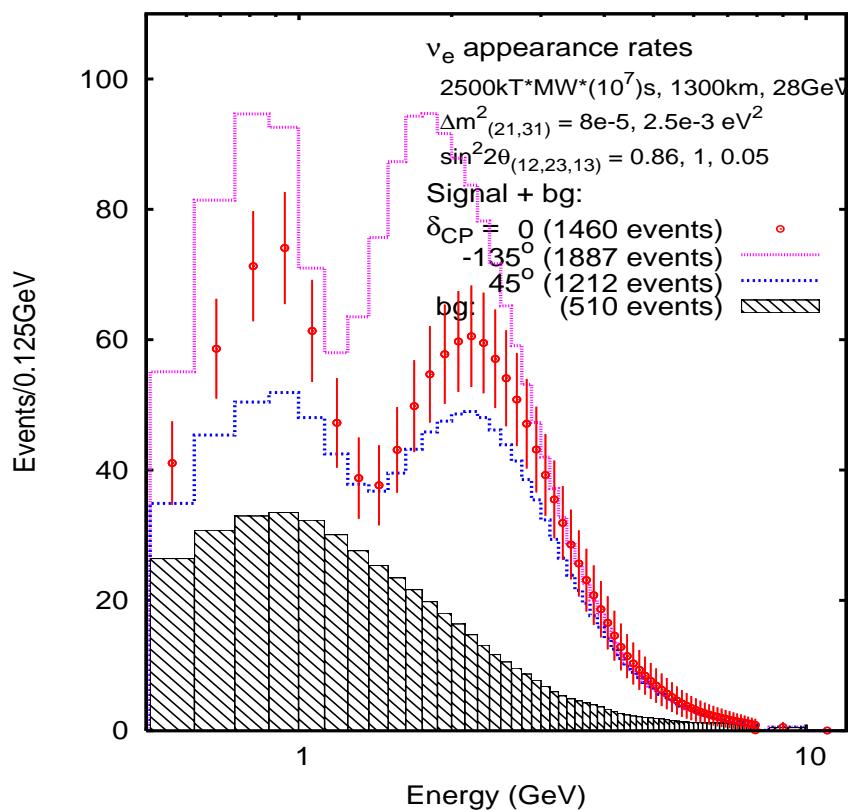


WBLE ν_e Appearance Spectra

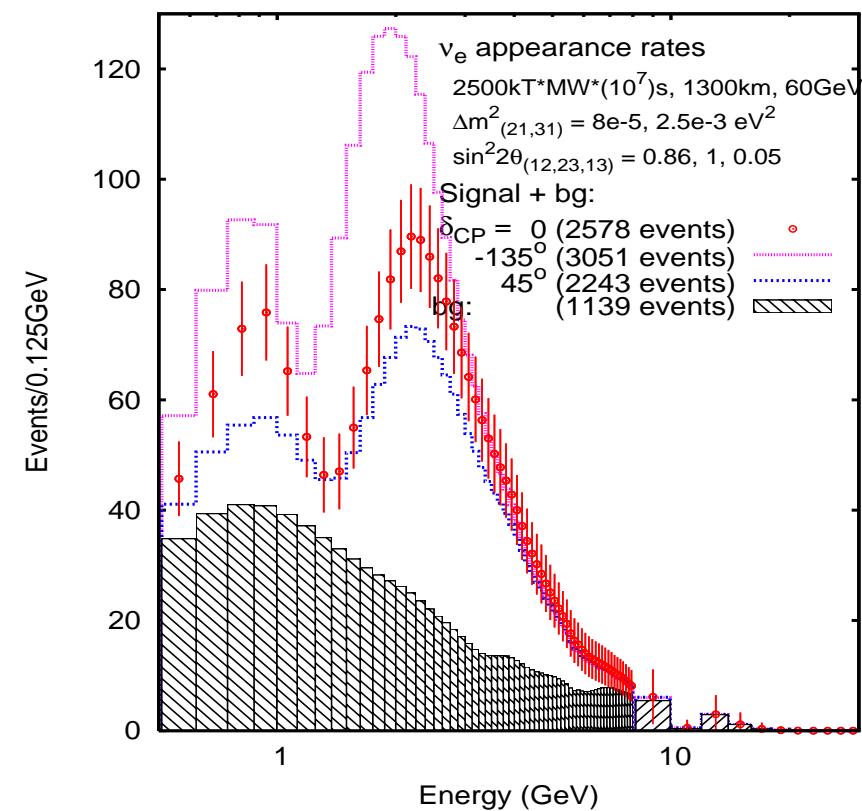
Parameterized Water Cerenkov Model in GLoBES.

$$\sin^2 2\theta_{13} = 0.05 \text{ 1300km at } 2500 \text{ MW.kT.}10^7 \text{ s.}$$

WBB 28 GeV



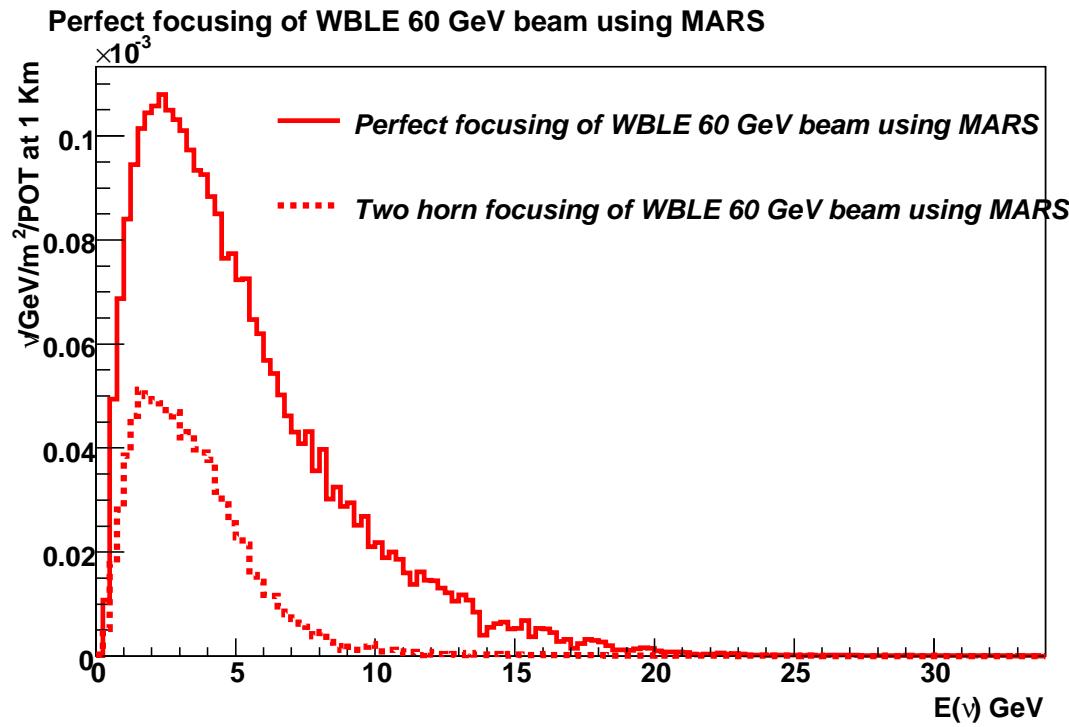
WBLE 60 GeV



60 GeV WBLE and 28 GeV WBB = similar sensitivities

NEW FOCUSING SYSTEM DESIGNS

"Solenoid Focus of Pions for Superbeams" H.Kirk. Talk given at NuFACT 06, Irvine, CA, August 28, 2006.



Solenoid as a Point to Parallel Lens

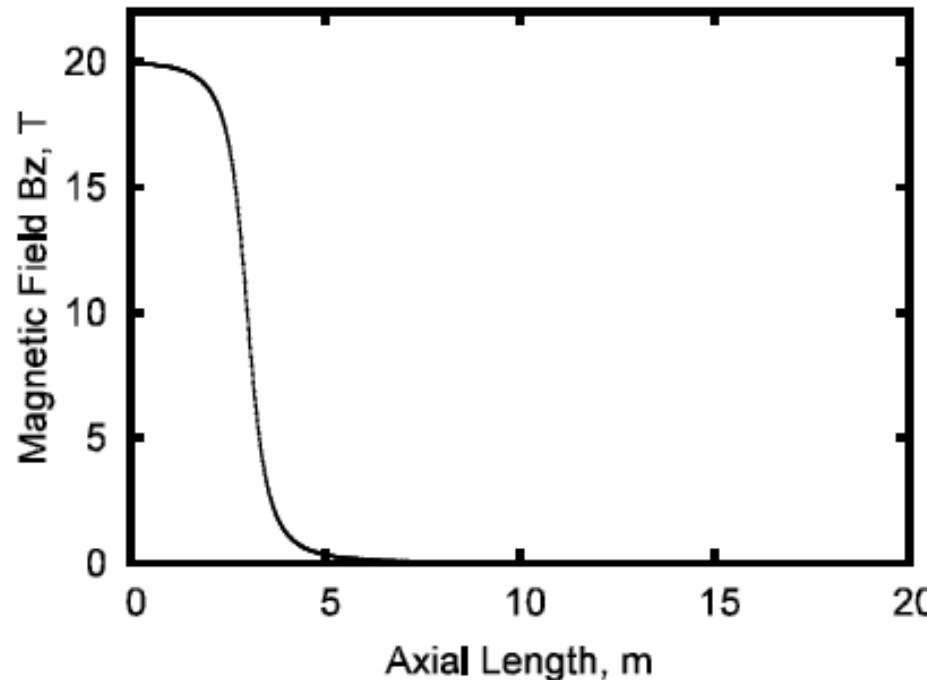
K.T. McDonald, *A Neutrino Horn Based on a Solenoidal Lens*, MUCOOL Tech Note 282

2.5.1 Neutrino Horn: Point-to-Parallel Focus, $L = (2n + 1)\pi cP/eB$

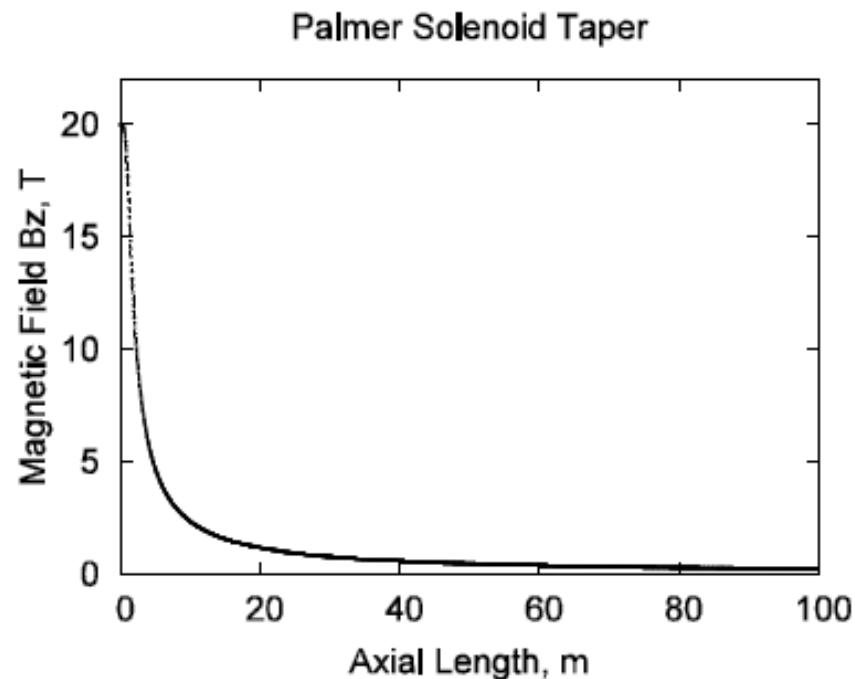
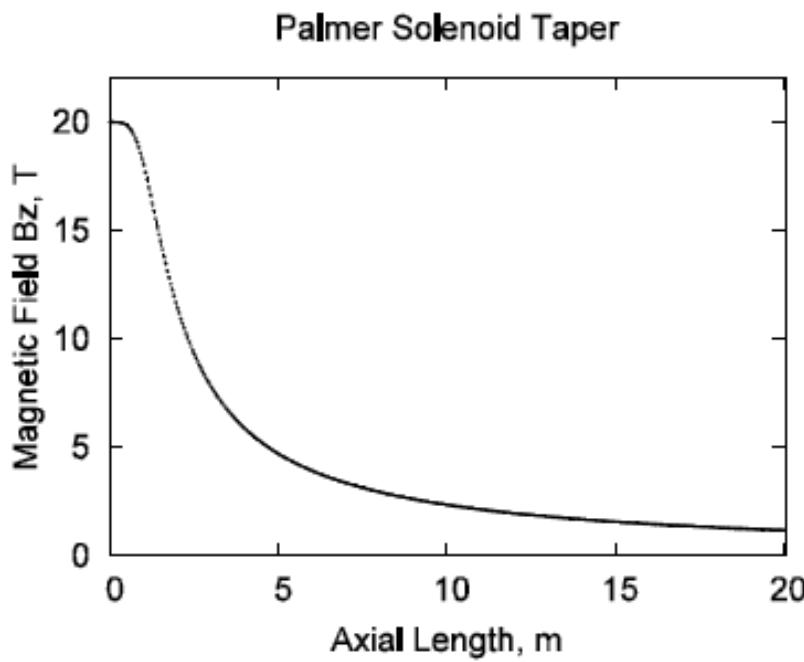
A solenoid magnet provides point-to-parallel focusing for particles produced inside the magnet, on its axis, with a discrete set of momenta P_n given by

$$P_n = \frac{P_0}{2n+1}, \quad (n = 0, 1, 2, \dots) \quad \text{where} \quad P_0 = \frac{eBL}{\pi c}. \quad (50)$$

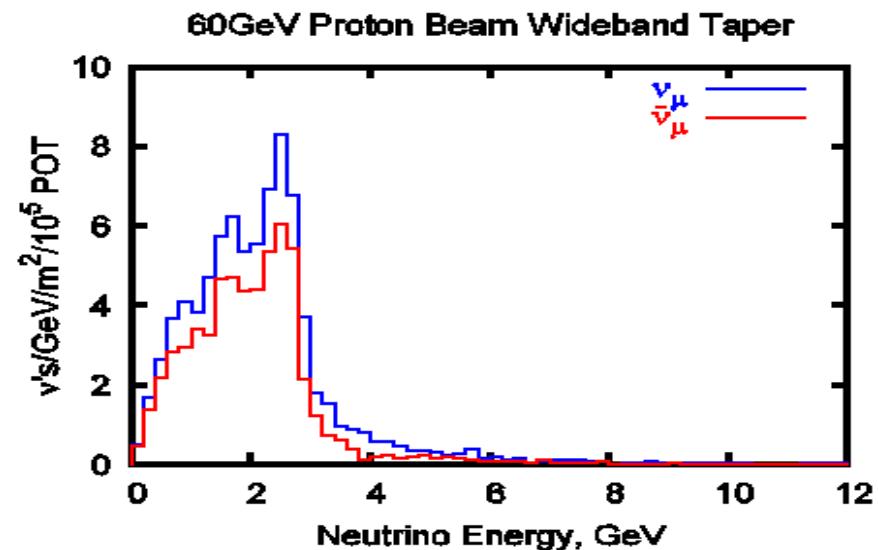
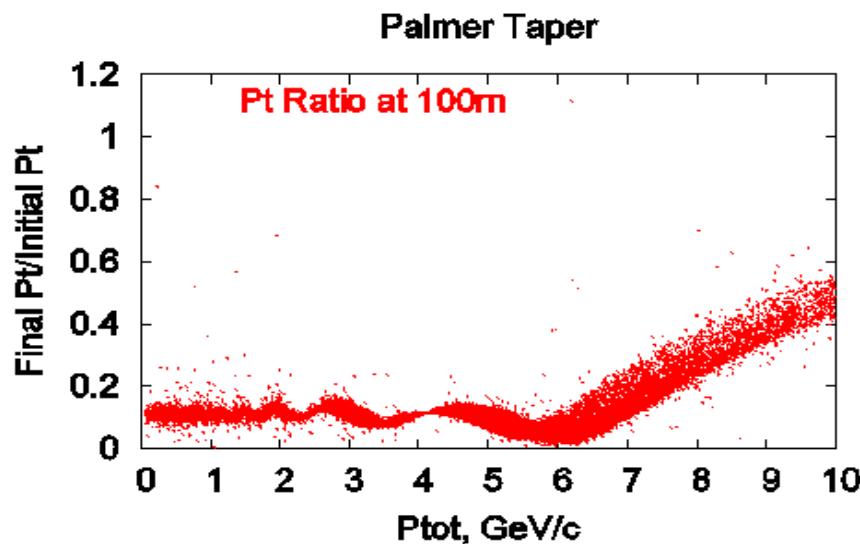
3m Solenoid Field



Taper for Wide Band Collection

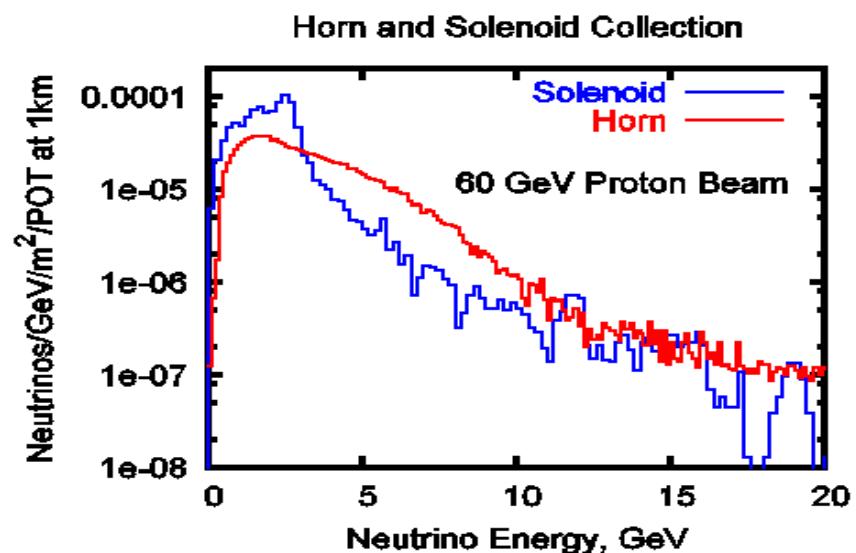


Solenoid vs Horn fluxes



PROs: Higher flux at lower neutrino energies. Smaller high energy tails \Rightarrow can use higher p-beam energies. DC operation = longer lifetime.

CONS: Beam is equal part ν and $\bar{\nu}$ = need magnetized detectors. Expensive.



Beam Design Milestones

- Detailed study of different FNAL beam power scenarios
- Conceptual design of beamline to DUSEL from FNAL
- Technical feasibility of a solid target for 1-2MW beam identified.
- Detailed definition/simulation of a WBLE beam from FNAL complete.
- Estimation of event and background interaction rates for on-axis WBLE beams and off-axis NuMI completed.
- Detailed simulation of on-axis event and background rates in a Water Cerenkov detector complete.
- Preliminary study of new focusing schemes = potential to run at higher energies.

BACKUP